Fraunhofer USA, Inc
Center for Experimental
Software Engineering
Maryland

Architecture Analysis of Evolving Complex Systems of Systems

Technical Presentation
Software Assurance Symposium
2008

Principal Investigator (PI): Dr. Mikael Lindvall, FC-MD

NASA POC: Sally Godfrey, GSFC

Team members:
Chris Ackermann, Dr. Arnab Ray, Lyly Yonkwa, Dharma Ganesan (FC-MD)
William C. Stratton, Deane E. Sibol (APL)

Fraunhofer Center for Experimental Software Engineering Maryland (FC-MD)
Fraunhofer Institute for Experimental Software Engineering (IESE)
Johns Hopkins University Applied Physics Laboratory Space Department Ground Applications Group (APL)

Outline

- Motivation
- Background: (static) SAVE
- Dynamic SAVE Vision
- Dynamic SAVE examples
- Applicability Throughout the Life Cycle

Problem/Approach

- Systems are often difficult to understand
  - – Systems of systems adds to the challenge
  - – Makes system verification difficult
  - – Interfaces often source of problems
- Approach
  - – Architecture analysis focusing on interfaces
- The new tool, Dynamic SAVE,
  - – extends the already existing *static* Software Architecture Visualization and Evaluation (SAVE) tool

Background: The (static) SAVE Tool

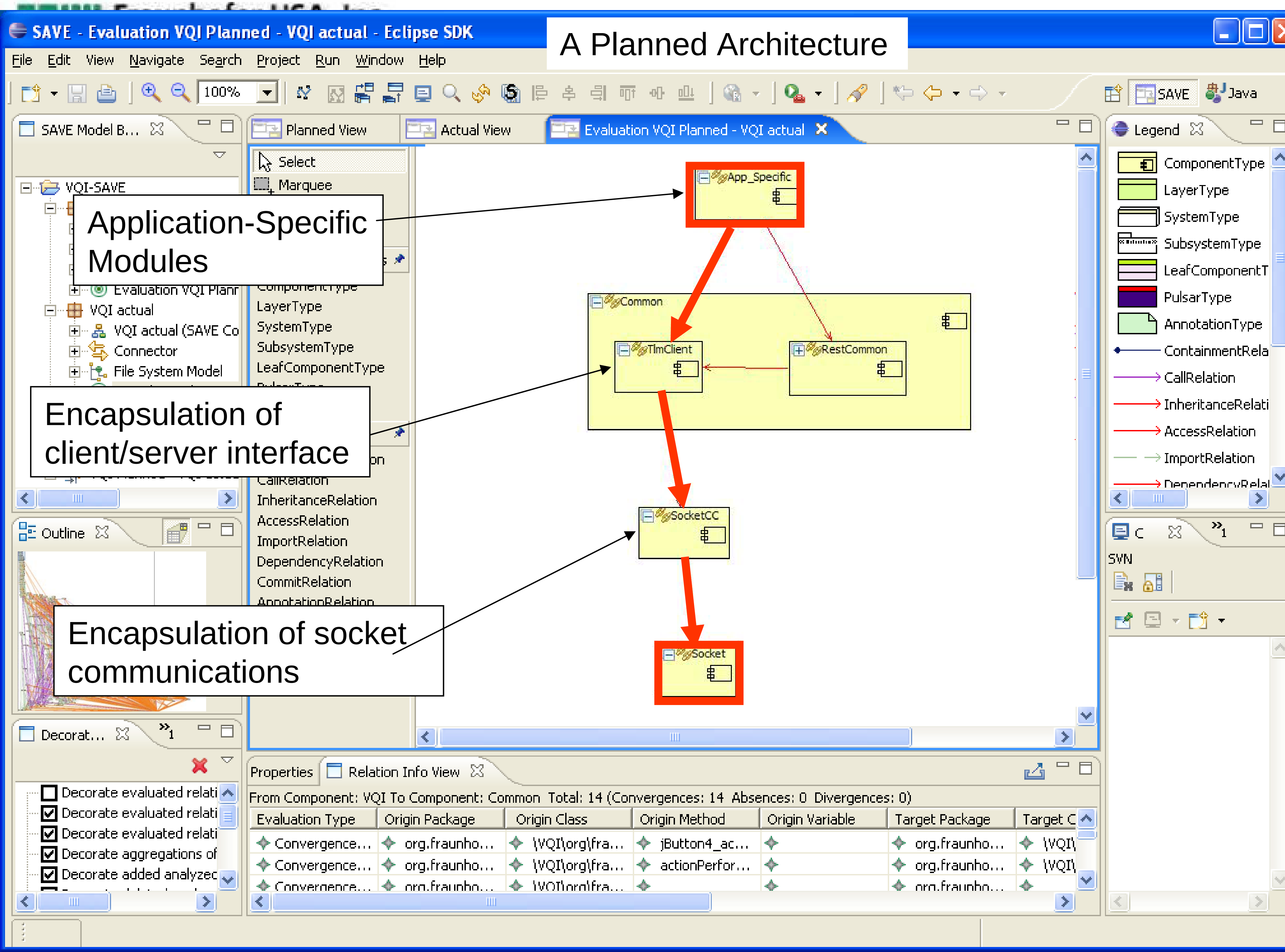
Software Architecture Visualization and Evaluation

- Does the actual implementation match the planned architecture?
  - Define a *planned* architecture
  - Create an *actual* architecture from source code
  - Identify architectural violations through comparison

- Applied to APL's Common Ground System
  - NASA Research Infusion project (Aerospace 2007)
  - (and other systems, e.g Core Flight System (cfs/cfe,) SNAS, White Sands)

- Conclusion
  - The SAVE approach is useful and practical
  - One can quickly model, visualize, analyze, find static architecture violations
  - Good for single software applications
  - **But for systems of systems, some questions remain unanswered…**

A Planned Architecture



Application-Specific Modules

Encapsulation of client/server interface

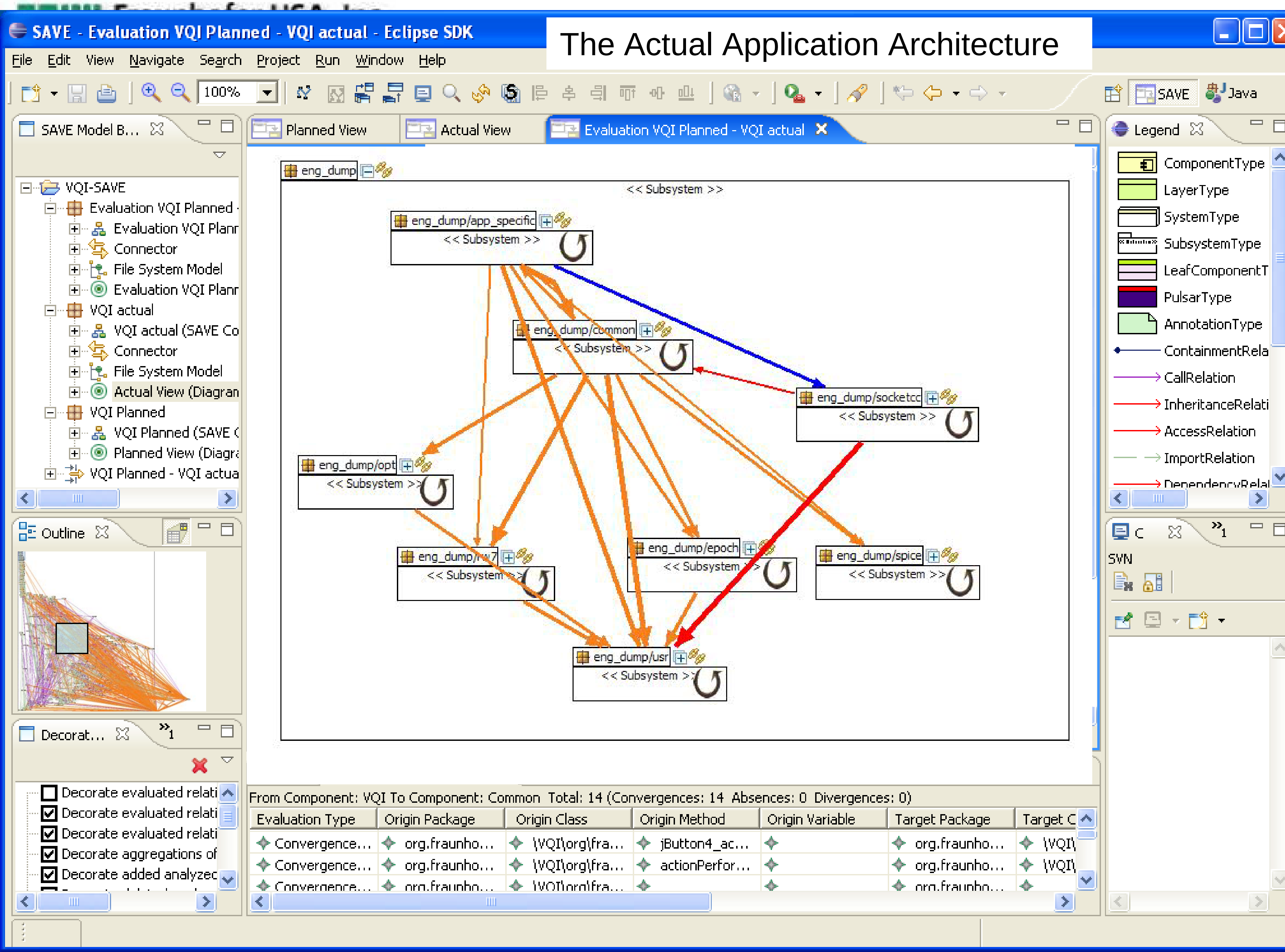
Encapsulation of socket communications

☐ Decorate evaluated relati
☑ Decorate evaluated relati
☑ Decorate evaluated relati
☑ Decorate aggregations of
☑ Decorate added analyzec

From Component: VQI To Component: Common Total: 14 (Convergences: 14 Absences: 0 Divergences: 0)

Evaluation Type	Origin Package	Origin Class	Origin Method	Origin Variable	Target Package	Target C
Convergence...	org.fraunho...	\VQI\org\fra...	jButton4_ac...		org.fraunho...	\VQI\
Convergence...	org.fraunho...	\VQI\org\fra...	actionPerfor...		org.fraunho...	\VQI\
Convergence...	org.fraunho...	\VQI\org\fra...			org.fraunho...	

The Actual Application Architecture



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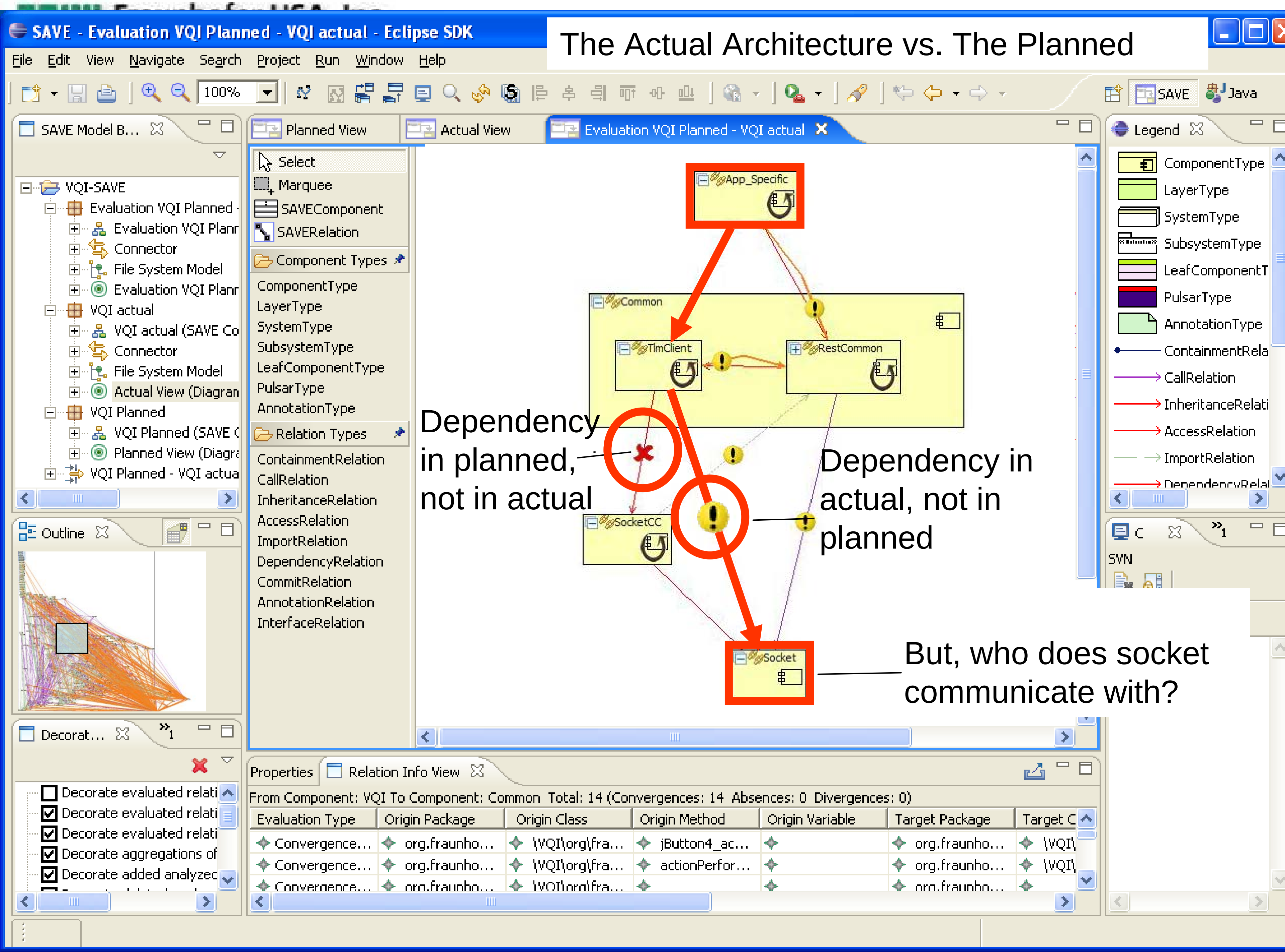
Convergence...	org.fraunho...	\VQI\org\fra...			org.fraunho...	

The Actual Architecture vs. The Planned



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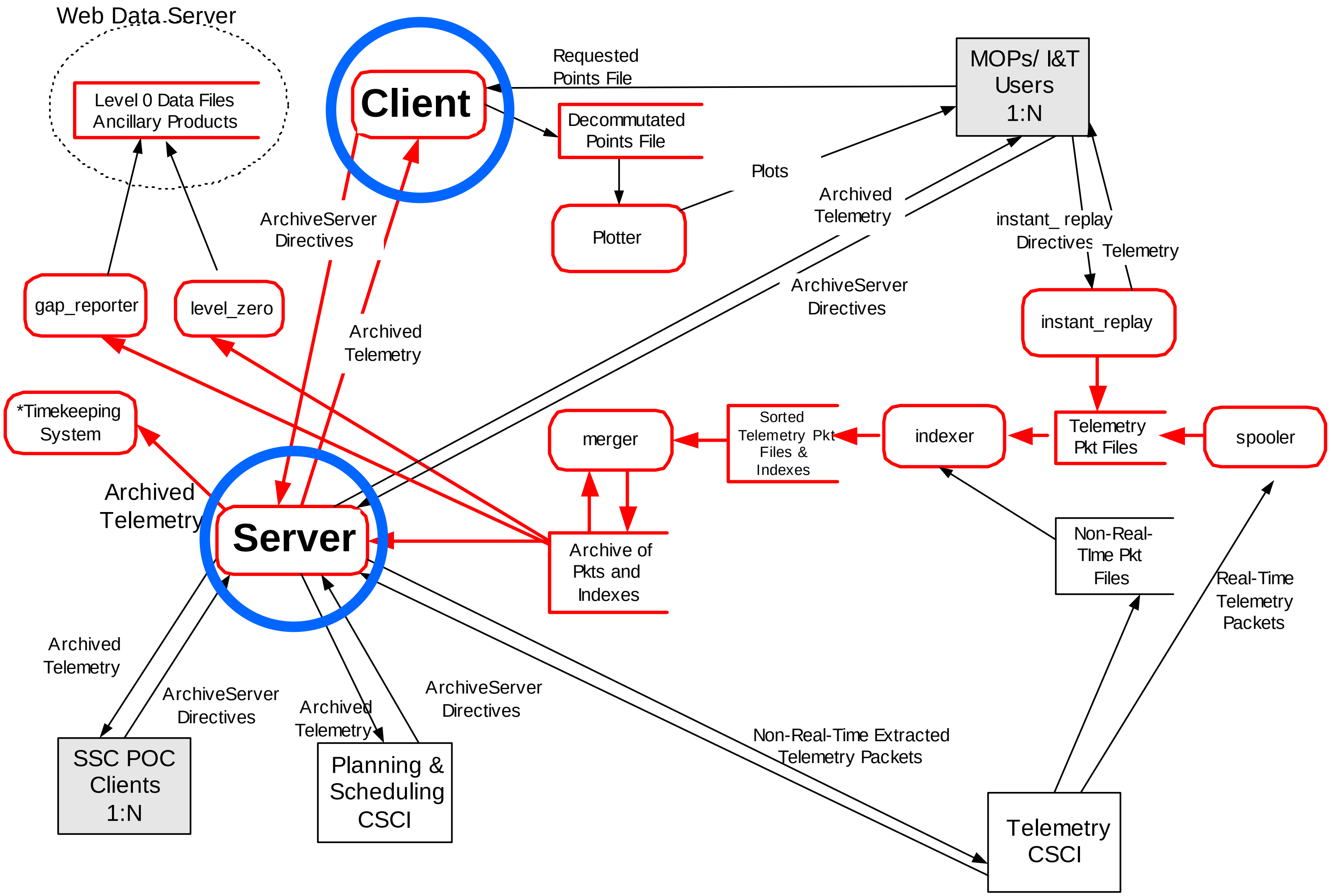
Dependency in planned, not in actual

Dependency in actual, not in planned

But, who does socket communicate with?

The Common Ground System

Assessment CSCI Telemetry Data Flow Diagram



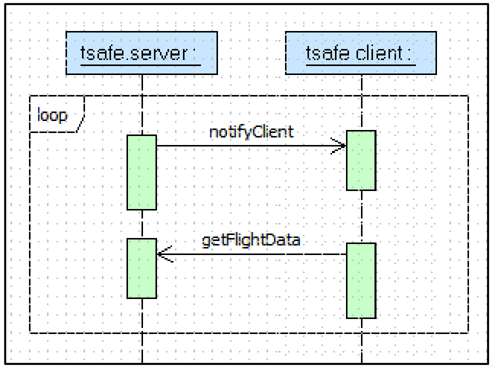
Dyn-SAVE Vision

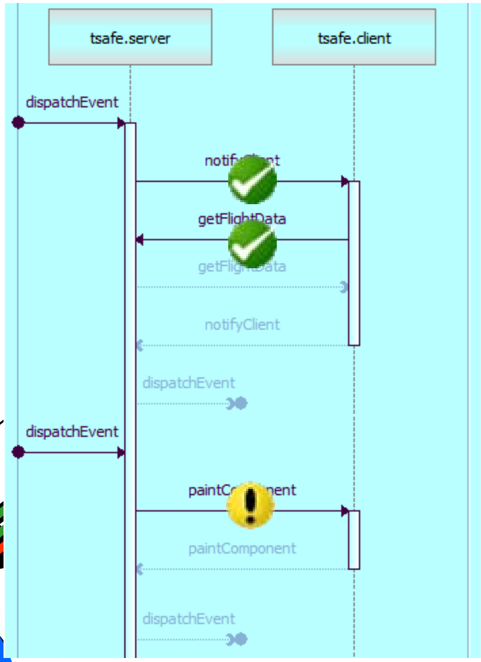
Compare Planned and Actual Behavior

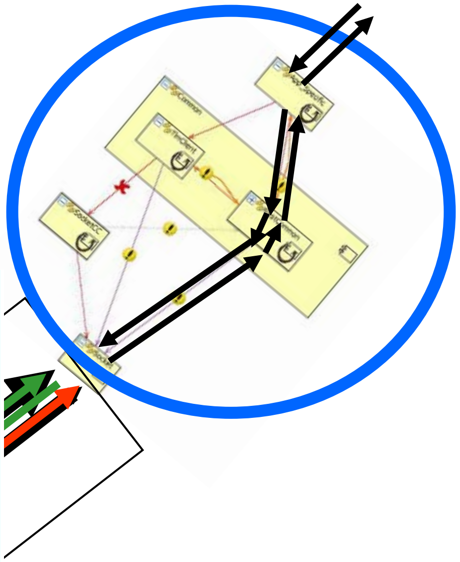
Form Actual Behavior

Telemetry **Client**

Specify Planned Behavior



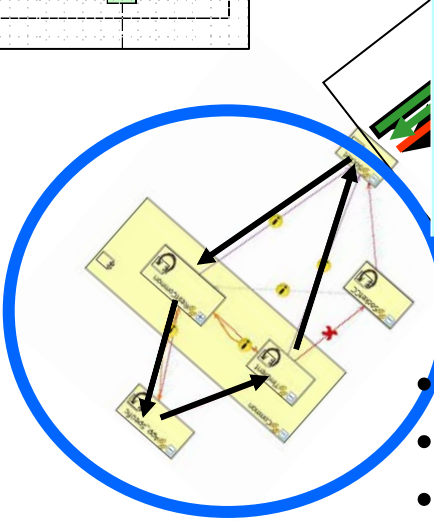




Capture Dynamic Information

Specify Level of Abstraction For analysis

Telemetry **Server**



- **Who does socket communicate with?**
- **Is communication according to specification?**
- **Check Sequences, Parameters, Values, Timing**

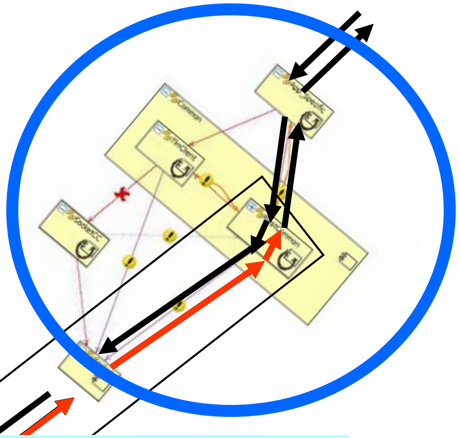
Dyn-SAVE Capabilities (Vision)

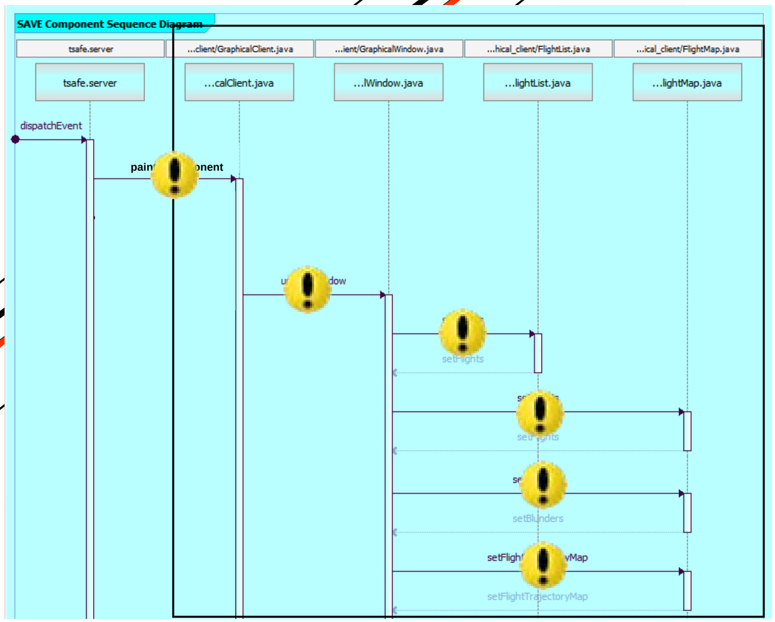
What components in the client are responsible for unspecified communication?

Compare Planned and Actual Behavior

Telemetry **Client**

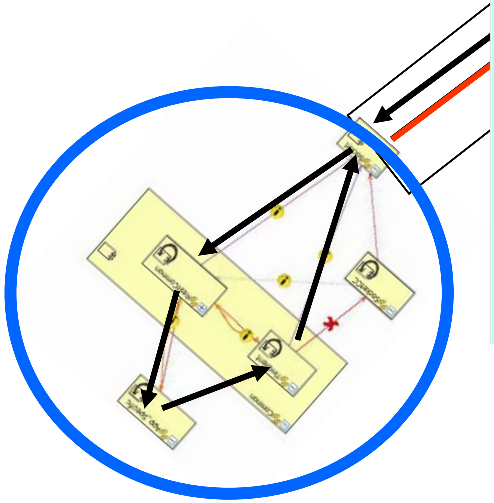
Form Actual Behavior





Reuse Planned Behavior

Telemetry **Server**



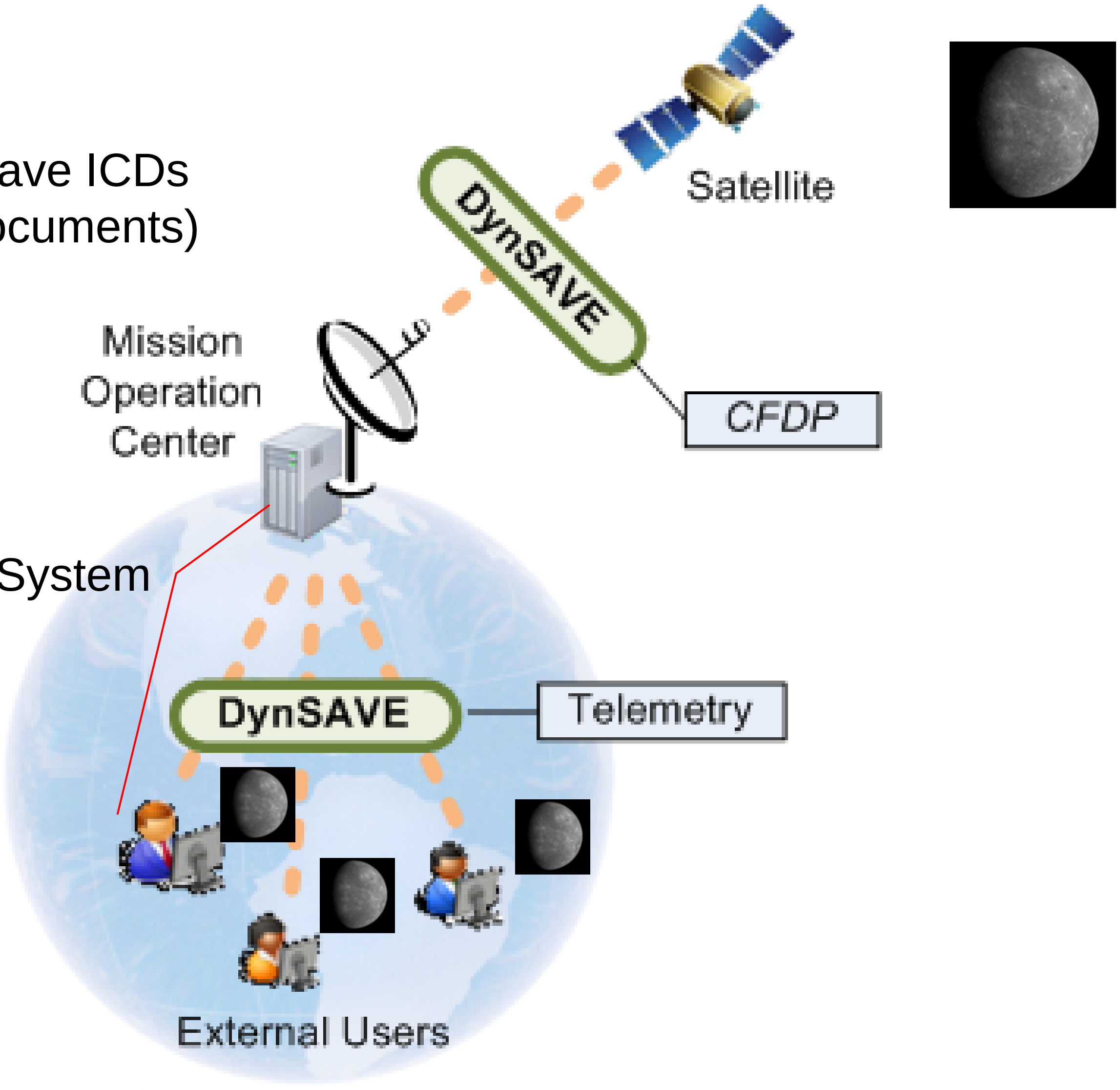
Specify Level of Abstraction For analysis

The Current Work
On Dynamic SAVE

DynSAVE in perspective

These systems all have ICDs
(Interface Control Documents)

The Common Ground System



Focus on:
Interface Control Documents

- NASA systems often developed by different teams
- Interface Control Documents (ICD) is key, but
  - ICDs often interpreted differently because
  - ICDs implicit, lack important details etc.
- Cause subtle critical deviations from specified behavior
  - Deviations difficult to detect
  - Emerging behavior difficult to predict
- Can result in severe problems, e.g. lost data, performance
- Need to
  - Detect deviations before deployment
  - (Specify expected and actual behavior before creating ICD!)

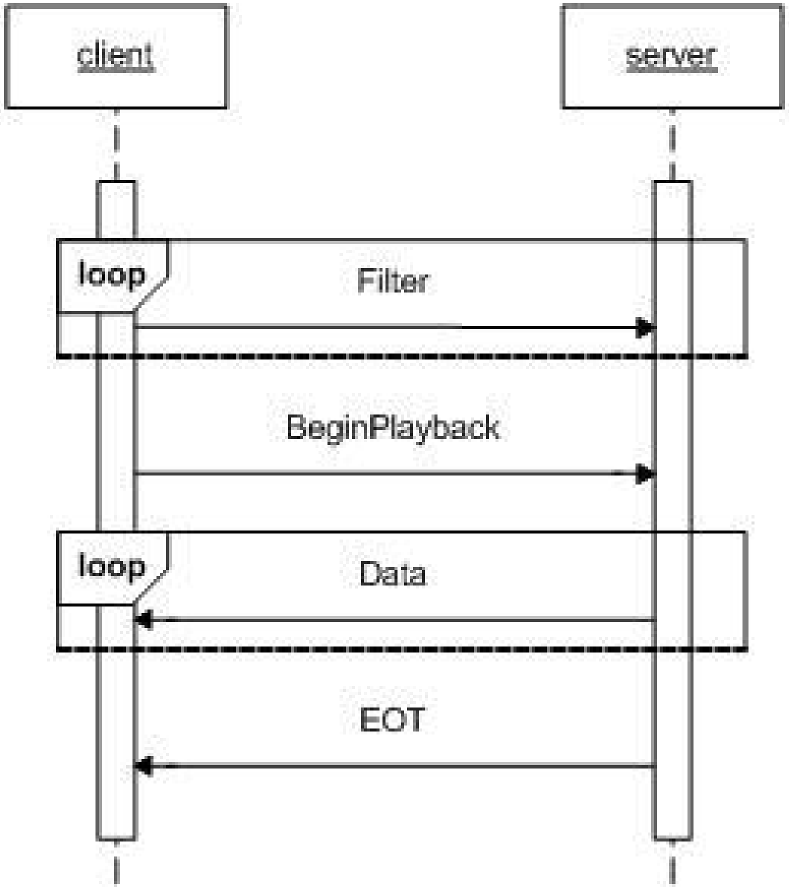
Research Questions

- Sequence diagrams
  - Can we use sequence diagrams to model, abstract, and detect such deviations?
  - Can sequence diagrams express what we need?
- Iterative modeling
  - Can we start with abstract models, add details as necessary?

Approach

- Collect concrete examples from APL
  - Model planned behavior
    - Use specification from ICD
  - Capture actual traces
    - Use Archive_Server and Eng_Dump
    - Generate Client scenarios, observe how Server responds
- Identify common patterns

Planned sequence diagram



The “simplest” diagram that describes the planned communication behavior described in the ICD

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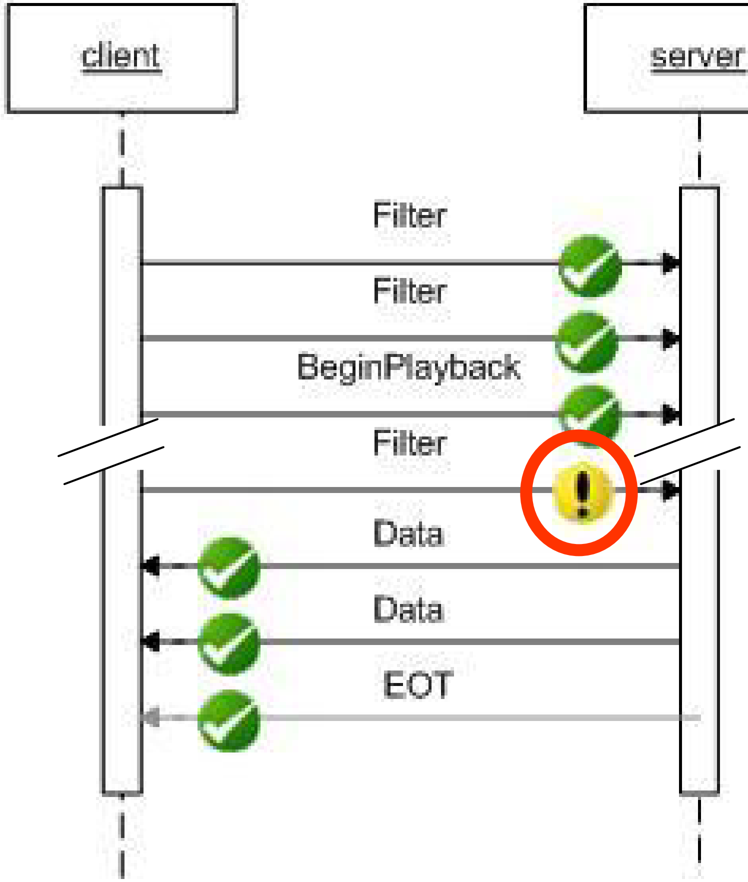
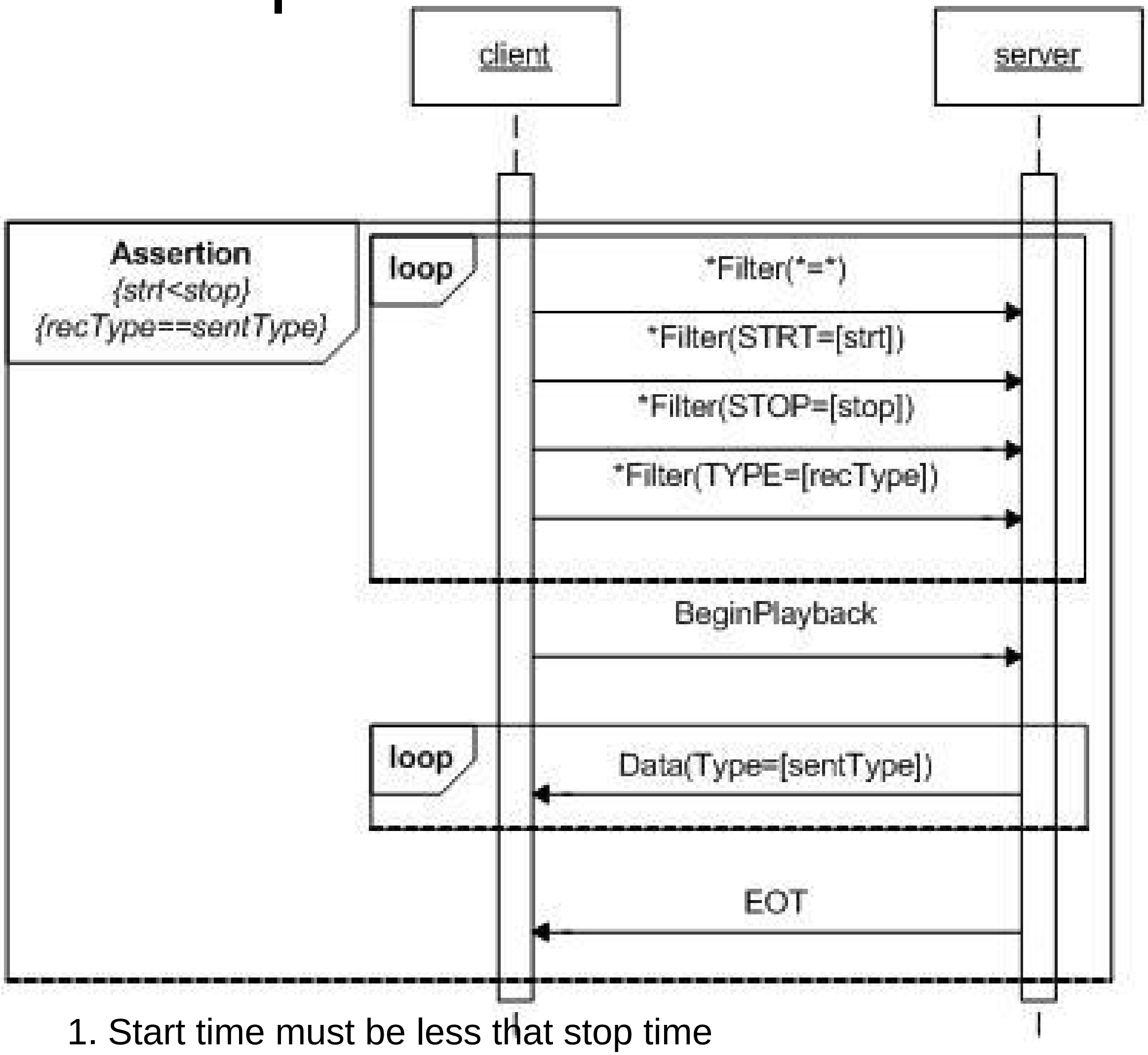
Example 1: Illegal filter



An illegal extra filter is sent after BeginPlayback and Data messages have been sent. The illegal filter is difficult to detect because it is in packet 869.

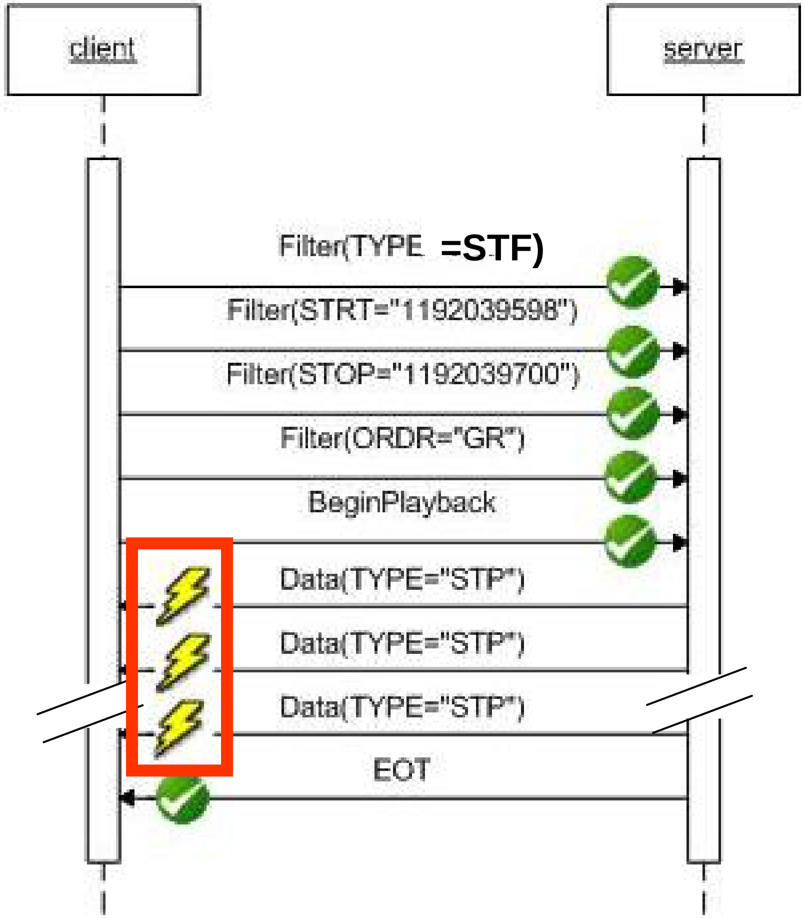
Detailed planned sequence diagram experimental notation



Rules:

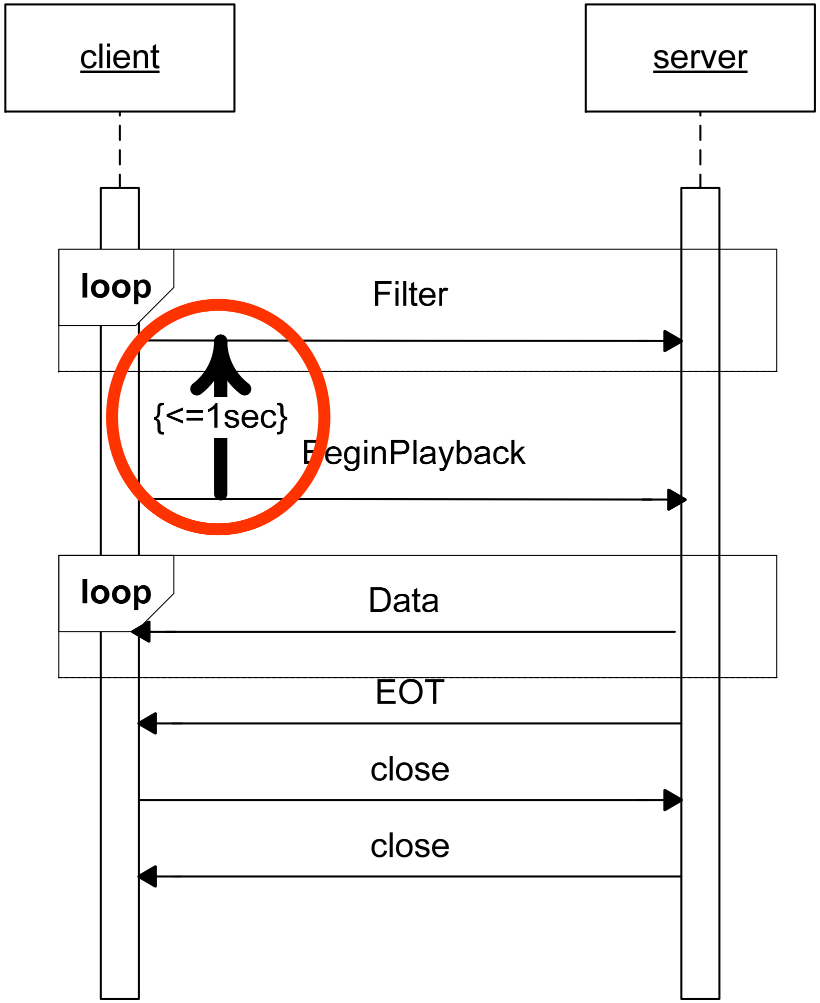
1. Start time must be less that stop time
2. Data type of each of the received data messages must match specification

Example 2: Illegal Type specification

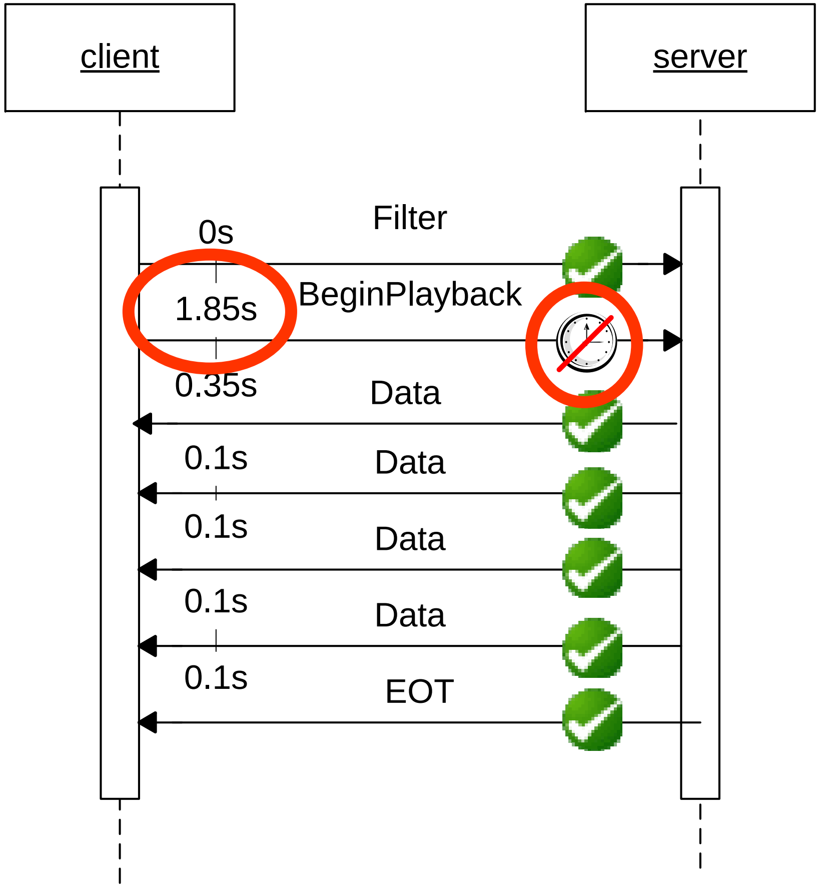


STF ordered – STP received.

Adding Timing Constraints

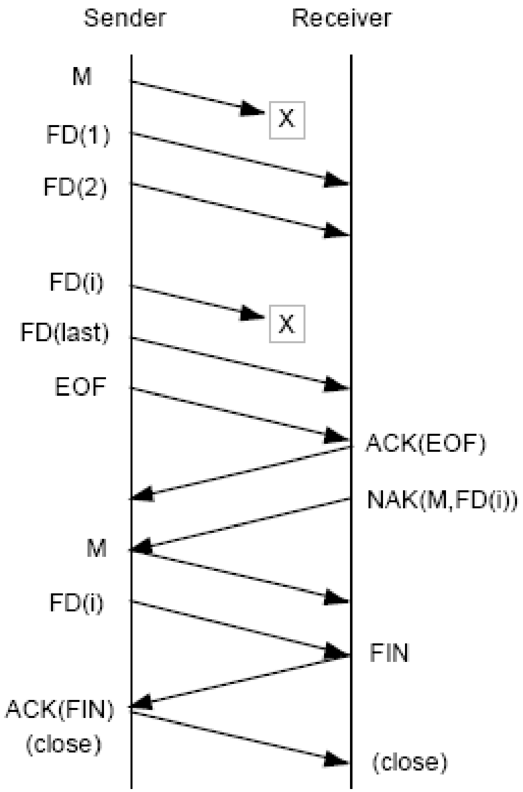


Checking for Timing Problems



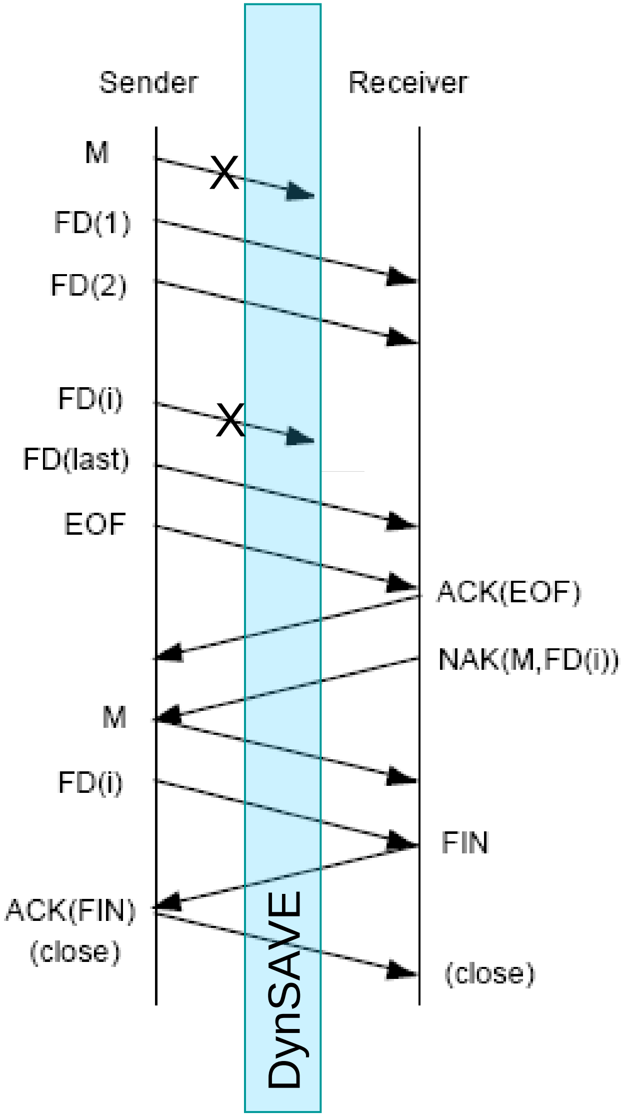
CFDP – A Mission Data System Protocol

- CFDP software provides reliable downloads of recorded on-board data
  - The implementation is distributed across flight and ground systems
  - The protocol runs on top of unreliable CCSDS command and telemetry layer
- At APL, CFDP is mostly automated, but…
  - Operators turn off CFDP uplink during critical command load sequences
  - Operators freeze and thaw timers so that pending transactions don't time out between contacts
- Improper CFDP operation can lead to unnecessary retransmissions, wasting precious downlink bandwidth

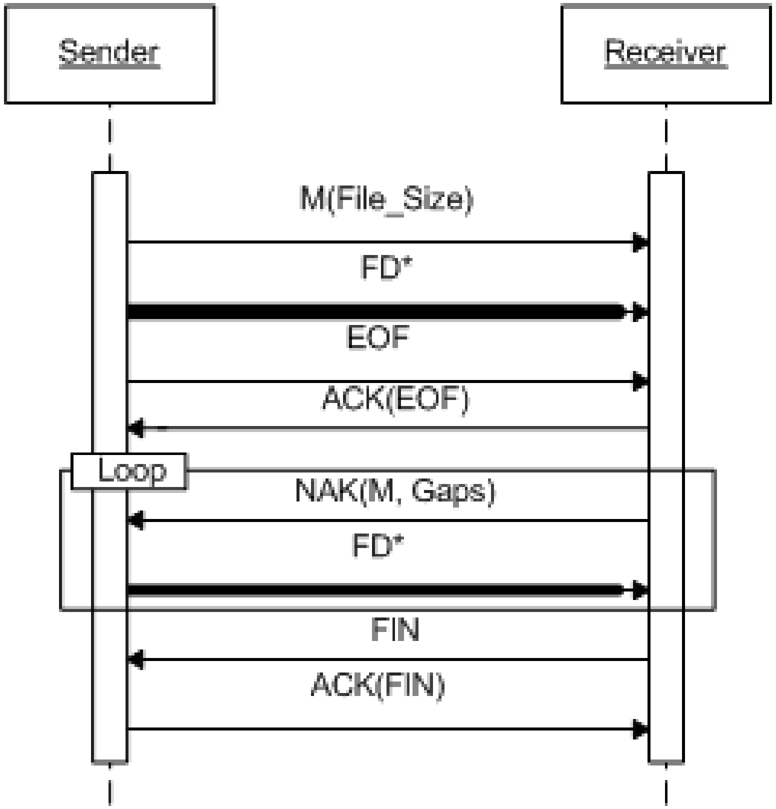


DynSAVE monitoring of CFDP

- DynSAVE monitors macro-level behaviors of the CFDP protocol without affecting flight or ground software
- DynSAVE could detect behaviors that are indicative of improper CFDP operation, for example:
  - timers were not frozen and uplink was disabled on the ground for an extended period, causing multiple retransmissions when the uplink was finally enabled again
- DynSAVE could detect behaviors that are indicative of issues in CFDP implementation, for example:
  - sender continues to send file data after the transaction has been cancelled
- These types of behaviors can go undetected (file transfers still work) but are important to detect (they can result in data loss!)



Planned CFDP Sequence



Rules:

1.Check that received FD are not NAKed *

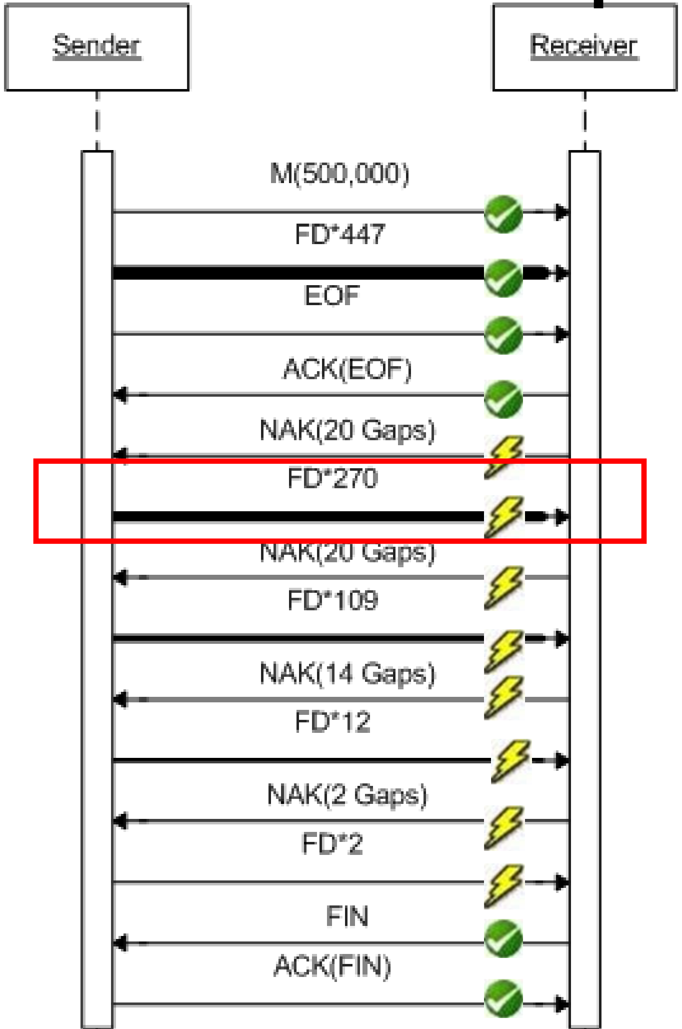
2.Check for duplicate FDs *

3.Check that we have all FDs upon FIN *

4.Check that identical NAKs are not sent back-to-back unless timer went off

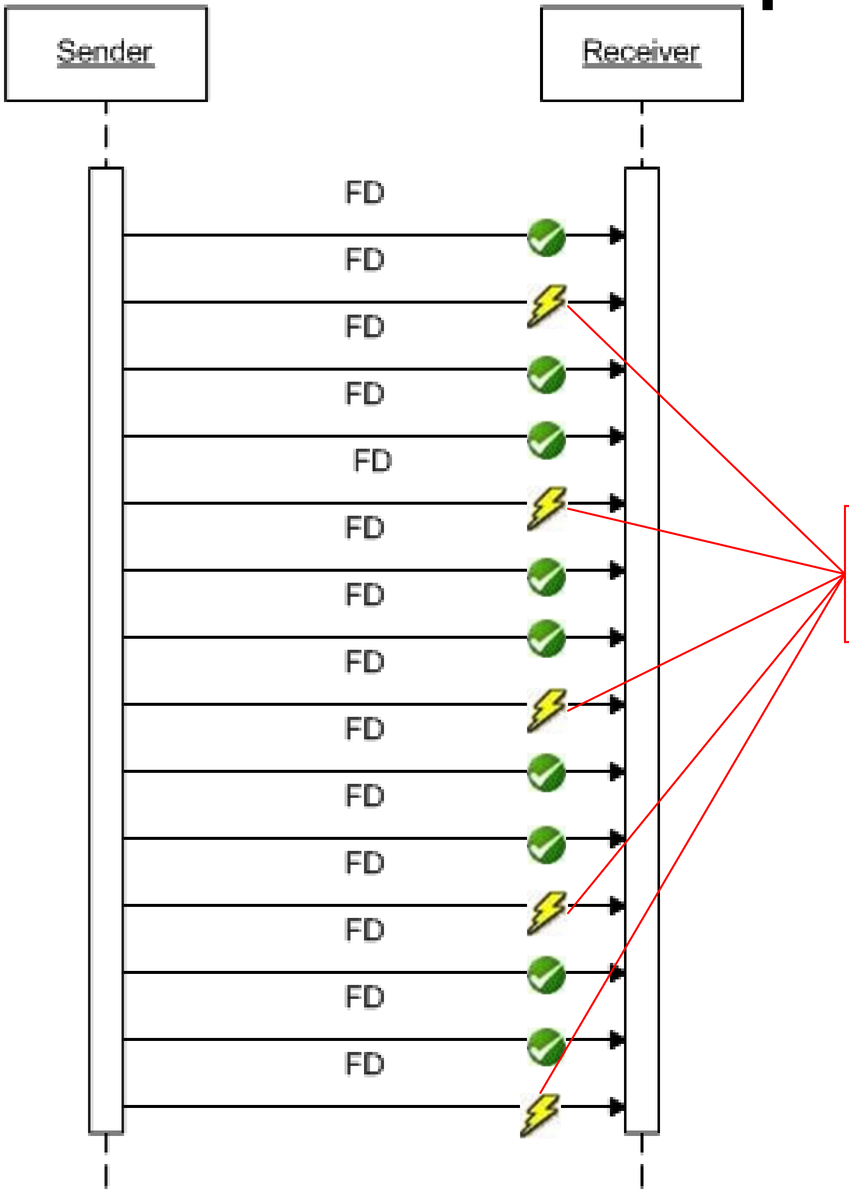
```
FileData: 482548-483544
FileData: 483545-484541
FileData: 484542-485538
FileData: 485539-486535
FileData: 486536-487532
FileData: 487533-488529
FileData: 488530-489526
FileData: 489527-490523
FileData: 491521-492517
FileData: 492518-493514
FileData: 493515-494511
FileData: 494512-495508
FileData: 495509-496505
FileData: 498500-499496
FileData: 499497-499999
EOF: Condition Code=No Error
ACK(EOF): Condition Code=No Error
NAK: 19940-20937;27916-28913;36889-37886;56829-
59820;72781-73778;76769-77766;82751-85742;101694-
102691;111664-112661;115652-116649;121634-
122631;130607-131604;139580-140577;146559-
147556;153538-154535;155532-156529;170487-
171484;197406-198403;203388-204385;220337-498500
```

Actual CFPD Sequence Annotated, Collapsed



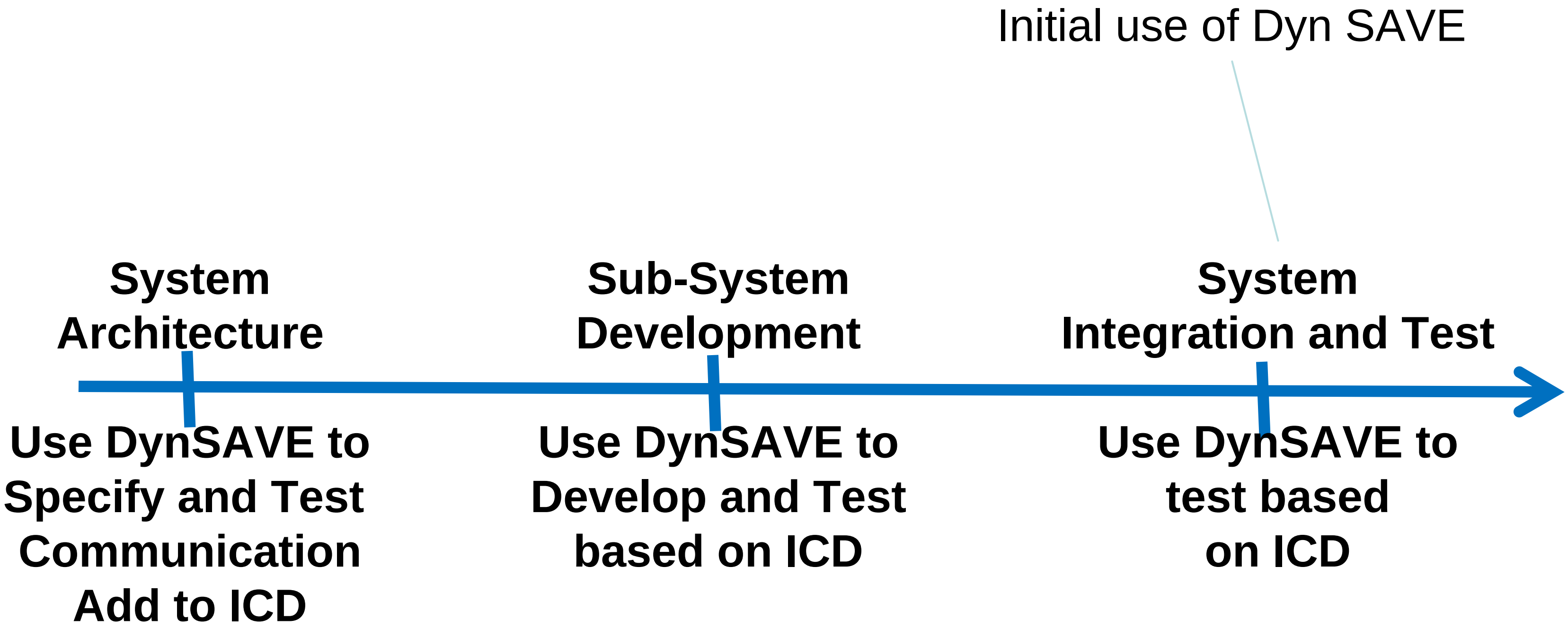
Needed FDs: 502
Send FDs: 840
Potential Waste: ~70%? – Further analysis needed.

Zoom in on CFDP sequence



Rule 2 Violation: duplicate FD!

Life Cycle Support



Initial use of Dyn SAVE

System Architecture

Use DynSAVE to Specify and Test Communication Add to ICD

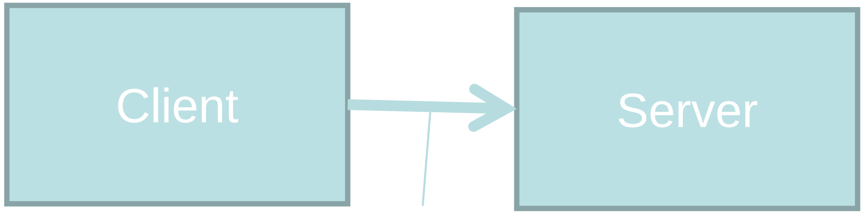
Sub-System Development

Use DynSAVE to Develop and Test based on ICD

System Integration and Test

Use DynSAVE to test based on ICD

Create System Architecture



Communication

No Server, No Client Exist

Use DynSAVE to

- Specify Planned communication
  - Sequences
  - Parameters, Values
  - Timing constrains
- Create Tests
  - Correct, Incorrect behavior
    - Specific incorrectness
    - Automatically generate defects
- Ensure that communication protocol can handle all tests
- Add Diagram, Specification, Tests to ICD
- “Generate” information for ICD

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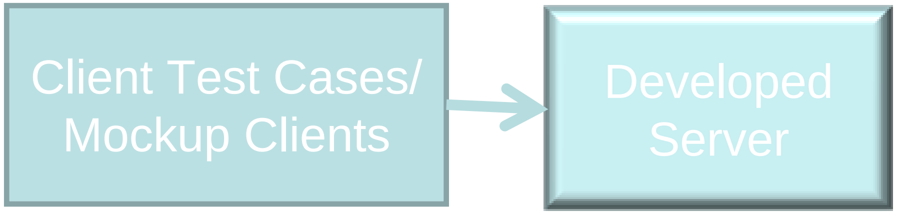
Sub-System Development

No Client (or Server) Exist

Server is built to ICD

Use DynSAVE to

- Import Planned spec from ICD
- Use Tests from ICD, create new
  - Correct and Incorrect behavior
- Ensure that Server can handle all tests
- Future research: Generate Mockup Clients (exe) for test
  - Remotely controlled Mockup
    - Turn on/off certain Mockup behavior
  - Run simultaneously on several machines



Status

- Dyn-SAVE works for telemetry protocol
- Currently adding functionality to evaluate CFDP protocols
- Applying Dyn-SAVE to APL’s systems
- We’d like to apply to other systems

Summary

- Analyze, Visualize, and Evaluate
    - structure and behavior using
    - static and dynamic information
    - individual systems as well as systems of systems
- Next steps:
    - Refine software tool support
    - Use approach to review, improve ICD
        - E.g. add planned sequence diagrams, rules to ICD
    - Apply to other systems to get feedback, understand needs

Architecture Analysis of Evolving Complex Systems of Systems

Executive Status Report
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Problem/Approach

- Systems are often difficult to understand
  - – Systems of systems adds to the challenge
  - – Makes system verification difficult
  - – Interfaces often source of problems
- Approach
  - – Architecture analysis focusing on interfaces
- The new tool, Dynamic SAVE,
  - – extends the already existing *static* Software Architecture Visualization and Evaluation (SAVE) tool

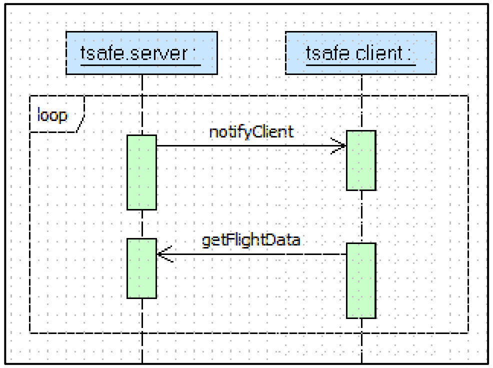
Dyn-SAVE Vision

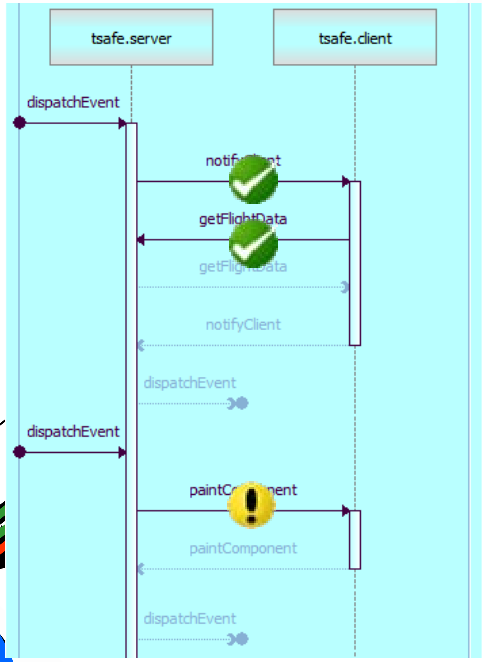
Compare Planned and Actual Behavior

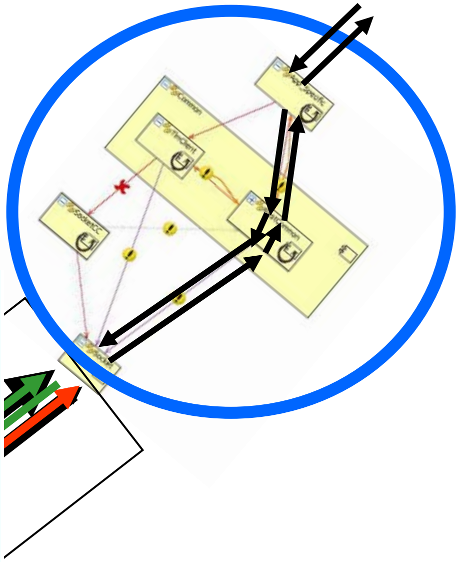
Form Actual Behavior

Telemetry **Client**

Specify Planned Behavior



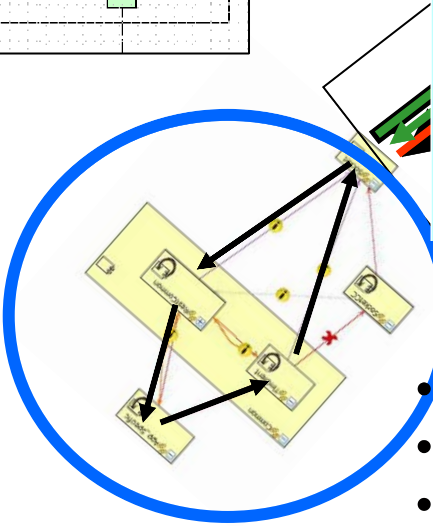




Capture Dynamic Information

Specify Level of Abstraction For analysis

Telemetry **Server**



- **Who does socket communicate with?**
- **Is communication according to specification?**
- **Check Sequences, Parameters, Values, Timing**

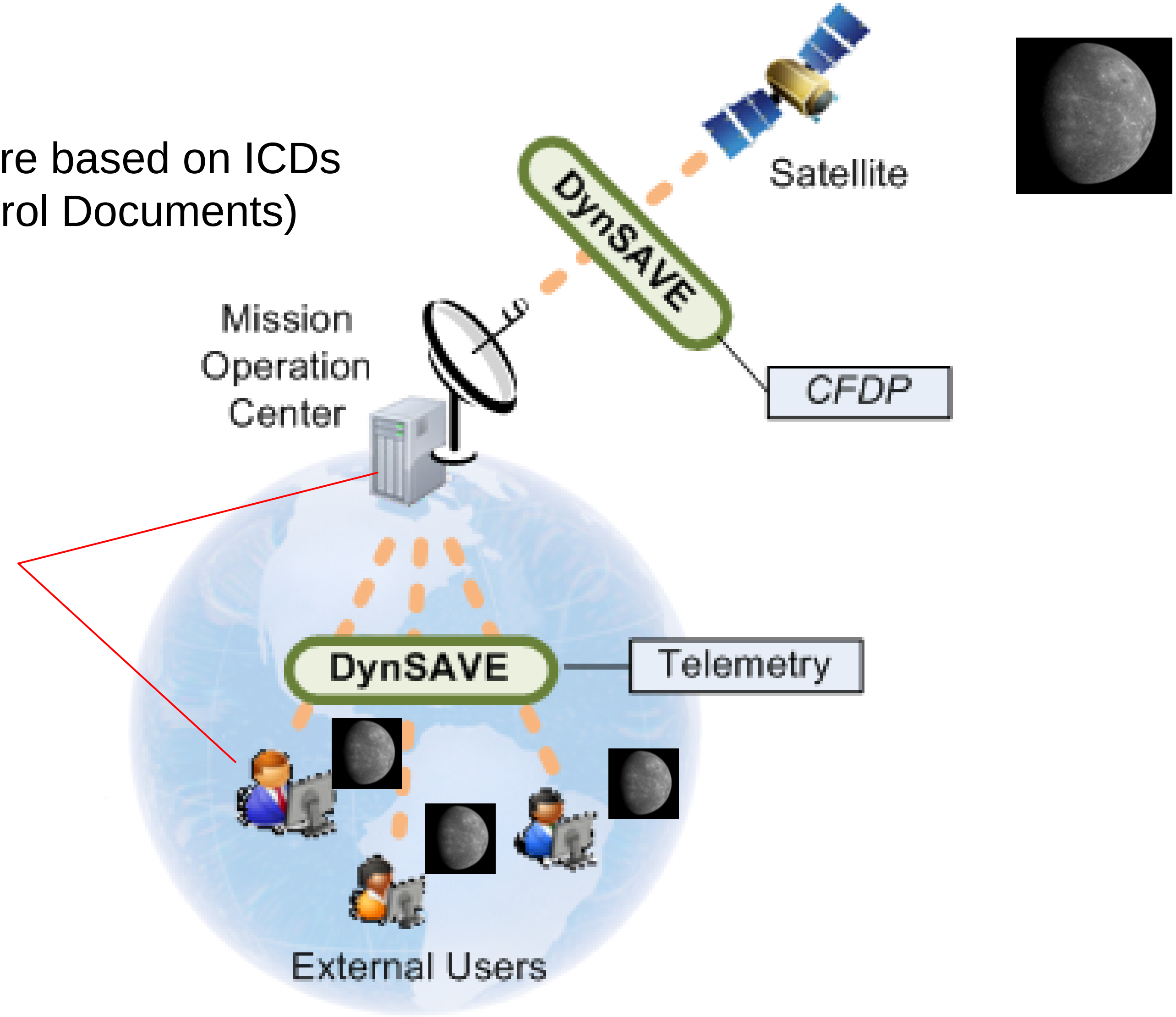
Relevance to NASA

- – NASA systems often developed by different teams
- – Interface Control Documents (ICD) is key, but
  - ICDs often interpreted differently because
  - ICDs implicit, lack important details etc.
- – Cause subtle critical deviations from specified behavior
  - Deviations difficult to detect
  - Emerging behavior difficult to predict
- – Can result in severe problems, e.g. lost data, performance
- – Need to
  - Detect deviations before deployment
  - (Specify expected and actual behavior before creating ICD!)

DynSAVE in perspective

These systems are based on ICDs (Interface Control Documents)

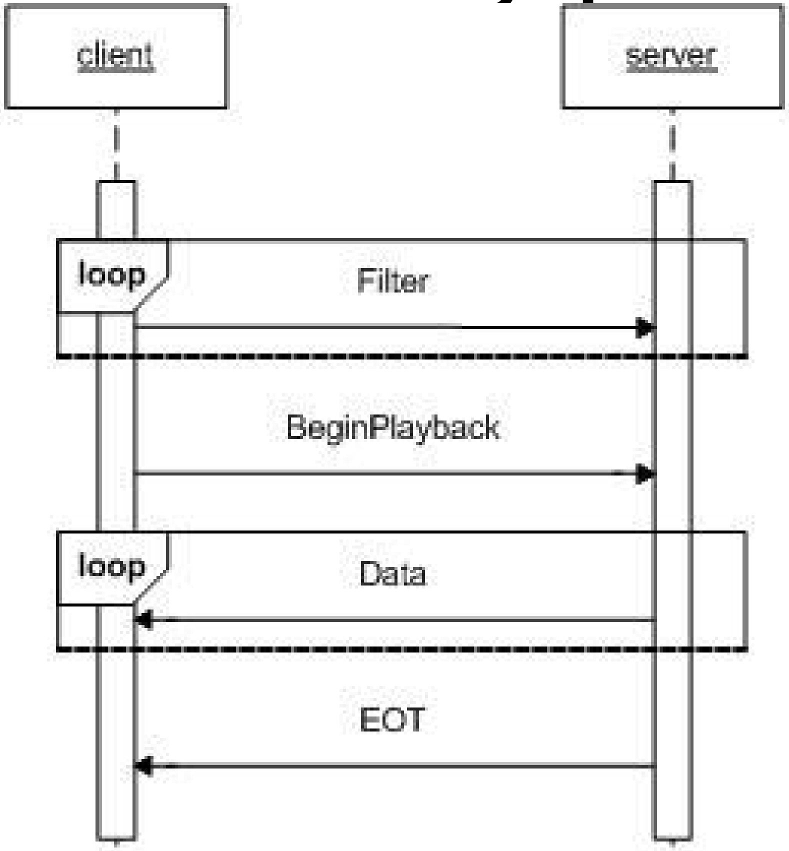
APL’s Common Ground System



Current capabilities

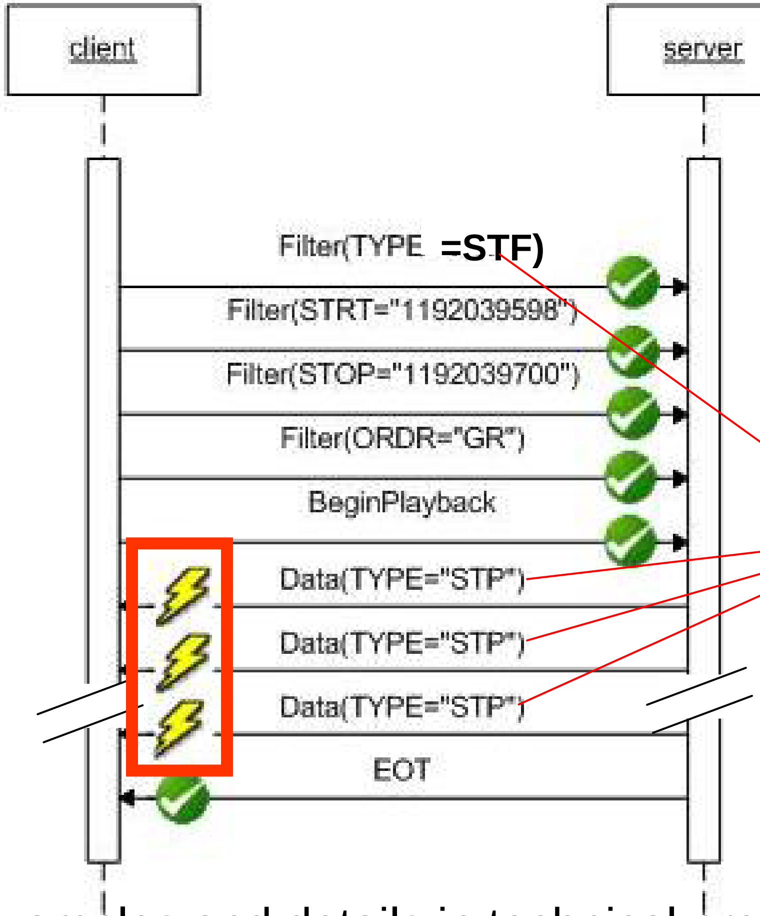
- Applied to APL's Telemetry protocol
  - See example below
- Currently Capabilities allows us to
  - Model planned behavior (based on ICD)
    - Sequences, Parameters, Values, Timing
  - Capture and parse actual communication
  - Visualize actual behavior
  - Compare planned behavior to actual
  - Automatically detect and visualize deviations
- Already detected some surprising deviations!

Abstract planned diagram for Telemetry protocol



The “simplest” diagram that describes the planned communication behavior described in the ICD.
Enhance in iterative fashion.

Detailed planned & actual



Illegal Filter Specification STF ordered – STP received

More examples and details in technical presentation!

Planned capabilities

Being able to

- Model Planned behavior of
  - – Ground system software
  - – Flight software
  - – Communication between Ground and Flight
    - e.g. CFDP
- Visualize actual behavior
- Compare planned and Actual behavior
- Automatically detect and visualize deviations

Technical challenges

- Difficult to use existing case tools to create planned sequence diagrams, e.g.
  - – Most only support basic diagrams
  - – Export formats often are not correct, usable
- Overcoming the problem
  - – Provide importers for case tool
  - – Provide our own sequence diagram editors

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  - static and dynamic information
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- Next steps:
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  - Apply to other systems
  - Apply earlier in system life cycle